DIAGNOSIS OF DYNAMIC ECCENTRICITY FAULT IN INVERTER-FED PERMANENT MAGNET SYNCHRONOUS MOTOR BASED ON ZERO SEQUENCE VOLTAGE COMPONENT

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Abstract— In this paper the finite element method is employed to simulate the healthy and faulty inverter-fed permanent magnet synchronous motor (PMSM). An on-line and non-invasive method based on zero sequence voltage component (ZSVC) for dynamic eccentricity fault diagnosis, which is independent of the load, for inverter-fed PMSM is proposed. The purpose of this method is to determine the frequency pattern due to dynamic eccentricity fault in the ZSVC signal for PMSM controlled by sensorless control ZSVC. Finally, some indexes are suggested for the fault detection.

Index Terms— PMSM, ZSVC, Inverter-fed, Dynamic eccentricity fault.

Introduction

The use of permanent magnet (PM) electrical machines in industry is rising due to their enormous advantages, such as high-power density, high efficiency and better dynamic performance compared to conventional machines, including induction machines. Eccentricity fault is an important fault in the PM machines in terms of occurrence rate and known as a progressive fault. Therefore, early detection of this fault is of paramount importance in order to prevent the fault expansion and further maintenance cost.

In [1], a fault detection method based on zero sequence voltage component (ZSVC) for induction machines has been presented. In addition, demagnetization fault detection method based on the ZSVC for PM synchronous motor (PMSM) has been introduced in [2]. Yet, there has never been a method introduced based on ZSVC for dynamic eccentricity detecting.

Fault diagnosis

To reduce the torque ripple and output current harmonics in PMSM, vector control with high precision can be implemented for control of the motor. This methods needs precise data of the rotor position which obtained through sensors fixed on the shaft of the motor. In addition to increasing the cost and geometrical size of the motor, this can decrease the reliability of the system. Therefore, many sensor-less methods have been introduced for more accurate control of the motor.

There are several sensor-less control techniques based on the 3rd harmonic of bemf (zero sequence voltage) [3, 4] which are very popular due to their simplicity and low cost. One problem of application of this technique is accessibility to the neutral in star-connected motor. Since current does nor pass the wire connected to the neutral, this wire is thin like signal wires and has no complexity.

Three methods have been introduced for measurement of the 3rd harmonic bemf and the most efficient and appropriate one is chosen for this measurement. Then mathematical analysis of the bemf under dynamic eccentricity fault in the PMSM is presented and the harmonics generated by the fault in the frequency spectrum of the bemf are determined.

Fig. 1 shows the overall plan of the drive of a BLDC machines with Y-connected resistance network in which measurement of the 3rd harmonic components of the bemf is possible. Three techniques are introduced for measuring the 3rd harmonic:

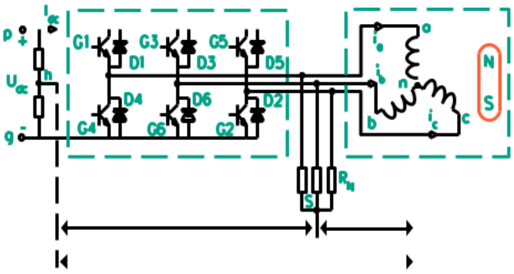


Fig. 1. Overall plan of the drive of a BLDC machines

1. Voltage u_{sa} between the neutral of Y of the resistance network and neutral of the stator winding n.
2. Voltage u_{sh} between s and middle of DC bus.
3. Voltage u_{nh} between n and h.

The Table I summarizes the different measurement techniques of zero sequence voltage

Table I. different measurement techniques of zero sequence voltage

Voltage	BLDC Mode	BLAC MODEL
u_{sn}	3rd harmonic of bemf	3rd harmonic of bemf
u_{sh}	50% of 1st harmonic of bemf+PWM noise	PWM Noise
u_{nh}	Sum of 1st harmonic of bemf of two active phases+ PWM noise	3rd harmonic of bemf+PWM noise

The inverter switches on ZSV occurring at high frequencies has no impact upon fault diagnosi sidebands and can be filtered. PMSMs are analyzed and effects of stator slots and non-uniform air gap caused by dynamic eccentricity are also investigated. The following frequency pattern is introduced for dynamic fault detection:

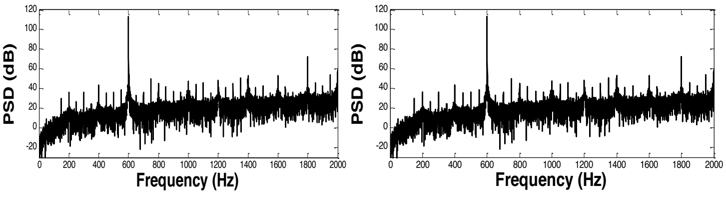
$$f_{eccentricity} = \left[(2\chi - 1) \pm \frac{k}{p}\right] 3f_s \tag{1}$$

where χ is 1, 2, 3.. and fs is the supply voltage frequency

Two-dimensional finite element method (FEM) is used to model the healthy and faulty motor. Distortion and imbalanced in magnetic flux and flux density, stator current and bemf caused by dynamic eccentricity fault are addressed. This fault increases the amplitude of sidebands in the frequency pattern (1) in the ZSV spectrum. By comparing the sideband components due to the dynamic eccentricity fault in the stator current and ZSV voltage sensitivity and high reliability of the proposed indexes compared with MCSA method is studied.

Results

Fig. 2 illustrates the spectra of the ZSVC of a healthy PMSM and a PMSM with 25% dynamic eccentricity fault in rated load and speed. Since the fundamental frequency of the ZSVC is $3f_s$, and f_s at the rated speed is 200 Hz, the fundamental frequency of the ZSVC is 600 Hz. It is indisputable that the dynamic eccentricity fault leads to an increase in the amplitude at the frequencies of 150 Hz, 300 Hz, 450 Hz, 750 Hz, and so on.



(a) (b)

Fig.2. Spectrum of ZSVC in nominal load and speed: (a) healthy PMSM and (b) 25% dynamic eccentricity fault

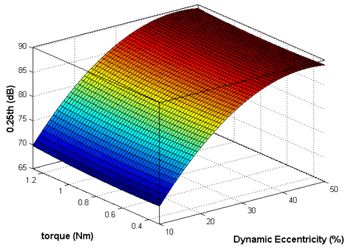
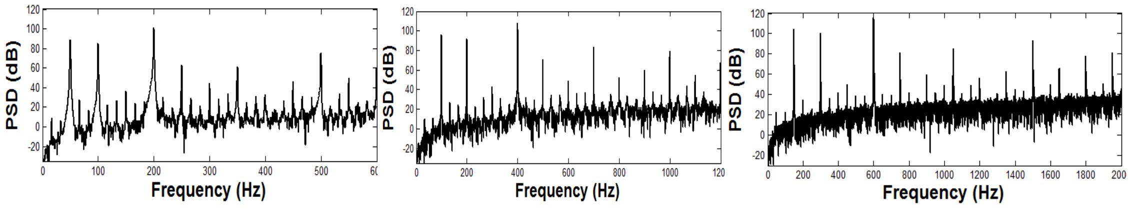


Fig.3. Effect of variation of load and eccentricity fault severity on amplitude of 0.25th harmonic

Moreover, in Fig. 3, the impact of variation of load and eccentricity fault severity on the amplitude of 0.25^{th} harmonic is demonstrated. From Fig. 2, it can be inferred that the sidebands are independent of the load, which is one of the most prominent characteristics of this index. It is concluded athat.

1. The proposed index is independent of the load variations and it is constant by increasing the load.
2. The speed rising leads to the increase of the proposed side-bands used for the fault diagnosis.
3. Investigation of the faults severity and comparing the generated side-bands components due to the dynamic eccentricity fault in the stator current and ZSV indicates that the introduced indexes in the ZSV have higher sensitivity and reliability with compared with that of the stator current.



(a) (b) (c)

Fig.4. Spectrum of ZSVC in nominal load at speeds: (a) 1000 rpm, (b) 2000 rpm and (c) 3000 rpm.

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